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REPORT OF THE MATERIALS RESEARCH COUNCIL (1974)

Maurice J. Sinnott

Michigan University

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REPORT

of

THE MATERIALS RESEARCH COUNCIL

December 1974

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College of Engineering
The University of Michigan
Ann Arbor, Michigan 48104
(313) 763-0242

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INTRODUCTION

This report provides a summary of the activities and output of the Materials Research Council for the year ending December, 1974, the seventh year of operation of the Council. Detailed technical papers and memoranda are in preparation for separate publication.

The Materials Research Council originated in 1966 when the Director of the Materials Sciences Office of ARPA suggested the possibility of assembling 20-30 experts in the materials field for an extended period each year to suggest feasible methods of attack on materials problems anticipated within DoD. The group was to be briefed on the current state of emerging problems and was to be challenged to develop solutions, or a consensus for approaches to the possible solutions of such problems.

The first study meeting of this group, which became known as the ARPA Materials Research Council (MRC) was held during the summer of 1968. The concept proved to be so fruitful that the MRC meeting was continued each year through 1974, and plans are currently being projected through 1975.

The Council has indeed occasionally worked on current high priority problems and expects to do so in the future, but the real value of the Council lies in its long-range and broad interdisciplinary vision of materials problems. A primary

strength of the Council lies in its ability to recognize and work on future critical needs, rather than on current critical problems.

The initial concept was that MRC membership should be drawn from the most able and highly qualified individuals in the country. The recognized abilities of the Council members in their respective fields has been such that the entire group, physicists, chemists, and engineers, have interacted in such a fashion that they are probably one of the most coherent, versatile and knowledgeable groups working in materials science and materials engineering in the country.

Since the MRC membership is drawn largely from the academic community it was felt that exposure to longer range materials problems would have a beneficial influence on research undertakings of Council members and their students. This has indeed been the case. Follow-on work from problems encountered in the Council has emerged at most of the institutions represented by the Council membership. Joint research efforts between faculty members at several institutions have resulted from interests developed from the various study meetings. Many graduate students and post doctoral fellows have actively pursued problems first formulated by the Council. They include such topics as surface chemistry, the physics of surfaces, fracture analysis, stress corrosion, plasticity, high-temperature thermodynamics, composite materials, refractory materials, electronic properties, optical properties, carbon thermodynamics, amorphous materials,

etc. The interdisciplinary nature of the group is reflected in the wide range of researches that have been generated as a result of the problems discussed in the Council. Even with the breadth and quality of talent on the Council, it has been necessary and desirable to invite consultants from universities, government, and industry in order to insure that the Council would be kept abreast of the state of the art. A list of those attending the 1974 meeting is included in the Appendix.

PROJECT ORGANIZATION

The technical direction of the ARPA Materials Research Council is delegated to a seven-man Steering Committee, which is representative of the various disciplines embodied in the Council. Membership on the Steering Committee is normally for a period of three years with replacements occurring each year. The functions of the Steering Committee are:

a) Work with ARPA to select problem areas for consideration by the Council.

b) Select Council members, specialists and consultants to work with the Council.

c) Evaluate and direct project activities.

d) Participate in project management.

The current Steering Committee is as follows:

Professor Howard Reiss
Secretary of the Steering Committee
Department of Chemistry
University of California
Los Angeles, California 90024

Professor Nico Bloembergen
Division of Engineering & Applied Physics
Harvard University
Cambridge, Massachusetts 02138

Professor Morris Cohen
Department of Metallurgy & Materials Science
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

Professor Willis H. Flygare
Noyes Chemical Laboratory
University of Illinois
Urbana, Illinois 61801

Dr. John J. Gilman, Director
Materials Research Center
Allied Chemical Corporation
Morristown, New Jersey 07960

Professor James Rice
Division of Engineering
Brown University
Providence, Rhode Island 02912

Dr. Robb M. Thomson
National Bureau of Standards
Institute for Materials Research
Washington, D.C. 20234

To carry out the work of the Council, a contract has been arranged between ARPA and The University of Michigan. The Project Director is Maurice J. Sinnott, Associate Dean, College of Engineering.

The following functions are performed by the University:

a) Coordinating planning, through the Steering Committee.

b) Providing a central, responsive contact point and clearing house for all Council affairs.

c) Negotiating consulting agreements with the project participants, and handling all administrative and financial affairs.

d) Publishing the reports issued by the Council.

The current contract terminates April 30, 1975.

The members of the Council in addition to the members of the Steering Committee are as follows:

Professor Michael Bever
Department of Metallurgy & Materials Science
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

Professor A. Bienenstock
Materials Science Department
Stanford University
Stanford, California 94305

Professor Bernard Budiansky
Division of Engineering & Applied Science
Harvard University
Cambridge, Massachusetts 02138

Professor Robert Coble
Materials Science Department
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

Dean Daniel C. Drucker
Engineering College
University of Illinois
Urbana, Illinois 61801

Professor Pol E. Duwez
W. M. Keck Laboratory of Engineering Materials
California Institute of Technology
Pasadena, California 91109

Professor Henry Ehrenreich
Pierce Hall
Harvard University
Cambridge, Massachusetts 02138

Professor John D. Ferry
Department of Chemistry
University of Wisconsin
Madison, Wiscorsin 53706

Professor Robert Gomer
James Franck Institute
University of Chicago
Chicago, Illinois 60637

Professor M. Fred Hawthorne
Department of Chemistry
University of California
Los Angeles, California 90024

Professor Robert A. Huggins
Center for Materials Research
Stanford University
Stanford, California 94305

Professor Walter Kohn
Department of Physics
University of California
La Jolla, California 92037

Professor Erastus H. Lee
Department of Applied Mechanics
Stanford University
Stanford, California 94305

Professor Donald J. Lyman
Materials Science & Engineering
The University of Utah
Salt Lake City, Utah 84112

Professor John L. Margrave
Department of Chemistry
Rice University
Houston, Texas 77001

Professor Frank A. McClintock
Department of Mechanical Engineering
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

Professor Elliott W. Montroll
Department of Physics & Astronomy
University of Rochester
Rochester, New York 14534

Professor Paul L. Richards
Department of Physics
University of California
Berkeley, California 94720

Professor Albert J. Sievers
Laboratory of Atomic & Solid State Physics
Cornell University
Ithaca, New York 14850

Professor Michael Tinkham
Department of Physics
Harvard University
Cambridge, Massachusetts 02138

Dr. George H. Vineyard
Brookhaven National Laboratory
Upton, Long Island, New York 11973

METHOD OF OPERATION

The major technical activity of the Council takes place each year during a one month summer study meeting. The summer meetings are organized so that small groups of two to six within the Council can meet and discuss problems in detail. In addition, short, somewhat larger group meetings are sometimes organized for briefing purposes. Such meetings are usually more structured, and typically involve three to ten Council members, up to fifty invited consultants and other DoD personnel. After these sessions, the Council members normally continue consideration of various problems raised and issue a meeting summary, and in some cases technical papers dealing very specifically with some of the points raised in the briefing sessions. Often the interest generated is sufficient to warrant follow-up visits by various Council members to DoD installations, and the organization and participation in short meetings covering extensions of the problem area. In many cases, the Council members maintain an active participation in an experimental or testing

program which follows the original consideration by several years.

The key to success lies in choosing appropriate Council members and consultants and in finding ways to couple their ideas to DoD needs.

PROBLEM SELECTION - BACKGROUND

In 1968 the Steering Committee, working with the ARPA Materials Science Office, arranged a series of briefings with various DoD agencies to examine those areas which were believed most appropriate for consideration by the Council. Four general topics were chosen for detailed examination:

Composite Materials

Shock Propagation

Constitutive Relations at High Temperatures and Pressures

Underground Sensing

At the 1968 summer conference, consultants and specialists worked with the Council to define more closely the problem areas, and to inform the Council members of related programs and progress. Individual members then worked either independently or in small subgroups on various segments of the problem areas and, after discussion and analysis, issued reports.

The original concept of holding a summer conference where the entire Council could devote its concentrated efforts to a few selected issues proved to be fruitful, but it was evident that more detailed preparation prior to the summer

conference was necessary in order to use the talents of the Council efficiently. Consequently, procedures were established for individuals or subgroups of the Council to undertake activities such as visits to DoD installations and DoD contractors or continuing investigations at home institutions in preparation for the following conference.

The technical report of the activities of the 1969 conference stimulated several meetings of the Council members with representatives of DoD laboratories. The results of this interaction were conveyed to the Steering Committee, enabling modification and addition of subject areas for the 1970 conference. Out of this meeting arose the following major areas of investigation:

1) Shock - continuation of efforts were to examine studies of the Grüneisen constant; electrical effects; dispersion by periodic structures; and dislocation structures.

2) Fracture - continuation of efforts to define crack propagation criteria, particularly in multiphased materials; define strain conditions at moving cracks; formulation of dislocation models of fracturing materials undergoing plastic deformation; and examination of surface energy considerations.

3) Composites - continuation of metal matrix composite investigation; examination of gradient composites; study of carbon composites; and analysis of wave propagation in composites.

4) Optics - continuation of analysis of laser glass materials problems; and optical properties of special composites.

5) New Materials - continued examination of materials and property measurements at extreme conditions of temperature; novel chemical combinations; and disordered carbon structures.

6) Stress Corrosion - continuation of survey of the field, examination of specific mechanisms.

7) Materials for Meeting Societal Needs - examination of superconductors for a magnetically suspended transportation system.

8) Bio-Materials - examination of materials compatibility in human bodies; materials problems in artificial organs; blood clotting; biological polymers.

The Steering Committee recommended after the 1970 meeting that the Council conduct more small meetings during the year for the purpose of preparing a given subject area for the summer conference. In this way it would be possible to have the necessary outside consultants contacted early enough to allow them to plan to attend portions of the conference and to identify, secure, and screen the relevant literature. Preconference organizational meetings were held for planning in the subjects of Environmental Degradation of Materials, Amorphous Semiconductors, and Stable Disordered Carbon Systems. It was proposed that aside from problem areas continuing or arising from previous Council activities, that a closer link be established between the Council and the ARPA Materials Science Director. In this way the talents of the Council could be brought to bear for the purposes of evaluation of future research directions

in a particular problem area so as to serve as a long-range advisory group for the ARPA Materials Science Director. This objective was carried forward in the selection of problems for the 1971 summer conference.

In line with the decision of the Steering Committee, several of the subject areas were organized into short meetings of one to three days duration. Considerable use was made of outside consultants with a structured program of presentations and a report of conclusions.

The 1971 activity in the remaining subject areas was carried out in the more traditional means by individuals or two to five man discussion groups. The subject areas are listed below:

Environmental Degradation of Materials
Materials Factors in Design with Brittle Materials
Gradient Materials
Infra-red Transmitting Materials
Amorphous Semiconductors
Stable Disordered Carbon Systems
Amorphous Metals
Applications of Superconductivity
Properties of Non-Biological Polymers
Fracture Mechanics
Materials at High Temperatures
Stress Waves in Composite Solids
Surface Thermodynamic Problems
Irreversible Thermodynamics
Solid Electrolytes

Prior to the 1972 meeting, pre-conference organizational meetings were held for planning in the case of the Environmental Degradation of Materials, Failure Prevention, and Design with Brittle Materials.

The areas of technical activity for the 1972 summer meeting are listed below:

Stress Corrosion Cracking
Surfaces of IR Laser Window Materials
Gradient Materials
Reliability of Brittle Materials
Prevention of Failures from Fracture
Materials Limitation in Advanced Energy Conversion Systems
Structure of Stable Disordered Carbon Systems
Strength Differential Effect
Wave Propagation in Composites
Materials Problems in Applications of Superconductivity
Fracture Mechanics
Structure of Non-Biological Polymers
Thermodynamic Properties of Materials at Very High Temperature
Structure of Amorphous Materials
Solid Electrolytes for Advanced Batteries
Recycling and Waste Disposal of Materials

The 1973 meeting had a total of eight short meetings. The subject areas are listed below.

Earthquakes and Mechanical Properties of Rock
Materials Problems in Solar Energy Conversion Systems
Scientific Barriers in Battery Systems
Superconducting Materials and Long Range Prospects
Testing for Brittle Materials Reliability
Materials Problems Related to Transmission and Reflection of Ultra-Violet Radiation
A Proposed Stress-Corrosion Cracking Handbook
Structure and Properties of Disordered Carbons

In addition to the above subjects, individuals or small group efforts in the following areas were undertaken.

Characterization of Amorphous Materials
Wave Propagation in Composite Materials
Gradient Materials
Fracture Mechanics
Materials for High Temperature Fuel Cells
Strength Differential Effects
Hydrogen Transportation Systems
Unconventional Materials Processing Schemes
Flywheel Energy Storage
Chemical Theories of Hardness

SUMMER CONFERENCE - 1974

The meeting was again held during the month of July at the Scripps Elementary School in La Jolla, California. A list of invited guests and consultants appears in the Appendix. The Steering Committee met in the Fall of 1973 to propose subject areas for inclusion in the 1974 meeting. A list of topics proposed by the ARPA Materials Science Office, together with some suggested by Council members was circulated to the Council for indications of interest. Final selection of subject areas and appointment of meeting chairmen was completed in a spring meeting in Washington. These meetings, together with the chairment, are listed below and summaries or outlines of the subjects discussed are included in the Appendix. In most cases, these sessions prompted one or more technical papers or notes and commentary.

High Velocity Erosion
Professor McClintock and Professor Hucke

Rain Erosion of Electromagnetic Windows
Professor Coble and Professor Hucke

Problems Relating to High Energy Laser Mirrors
Professor Bloembergen

Solar-Energy Systems - Materials Problems
Professor Cohen and Professor Ehrenreich

Degradation of Materials in Energy-Related Systems in the Presence of Hydrogen
Professor Hirth

Conservation of Materials
Professor Bever and Professor Thomson

Fundamentals of Forming of Brittle Polymers
Professor Bever

Status of Metal Matrix Composites
Professor Bever and Professor Duwez

In addition to the work directly related to one or more of these meetings, small group or individual efforts were undertaken in the following subjects:

Plastic Processing of Brittle Ceramics
Theory of Surfaces and Interfaces
Materials Strategies and Alternatives
Fracture Theory
Wave Propagation in Composite Media
Flywheels
High Energy Battery Systems
Polymeric Structures
Chemical Factors in Flow and Fracture
High Energy Explosives

As in the past, considerable use was made of a computational system utilizing the University of Michigan Computing Center via telephone. Professor B. Carnahan was available to help formulate and solve the member's computational problems.

In addition, representatives of various service and governmental bodies were invited to provide a two-way communication with the Council. In this manner, the results of the Council's efforts could be more directly communicated to DoD and other government groups working in the materials area. Also, the problem areas most deserving of consideration could be discussed with the Council so that they might be considered as topics at future conferences. The following representatives attended portions of the conference:

C. F. Austin, Naval Weapons Center

J. M. Bennett, Naval Weapons Center

H. E. Bennett, Naval Weapons Center

J. Bryan, Lawrence Livermore Laboratory

H. H. Caspers, Naval Electronics Laboratory Center

G. Daly, ERDO

A. G. Evans, National Bureau of Standards

A. G. Gaar, Naval Weapons Center

A. J. Glass, Lawrence Livermore Laboratory

J. C. Halpin, Air Force Materials Laboratory

G. A. Hayes, Naval Weapons Center

M. K. Hubbert, U. S. Geological Survey

G. W. Leonard, Naval Weapons Center

C. F. Markarian, Naval Weapons Center

H. G. Nelson, Ames Research Center

A. Peterlin, National Bureau of Standards

H. E. Rast, Naval Electronics Laboratory Center

W. H. Reichelt, Los Alamos Science Center

S. Ruby, Advanced Research Projects Agency

T. T. Saito, Air Force Weapons Laboratory

D. G. Schueler, Sandia Laboratories

D. M. Schuster, Sandia Laboratories

C. M. Stickley, Advanced Research Projects Agency

R. P. Stromberg, Sandia Laboratories

E. C. van Reuth, Advanced Research Projects Agency

C. A. Wert, National Science Foundation

As in prior years, the results of the Council's effort are divided into two broad categories; namely, 1) papers in a state ready for publication, and 2) reports and memoranda for

limited distribution representing work in progress. The former category is available for general distribution and, in most cases, are in the process of publication in the appropriate technical journals. In many instances, the reports arising from the 1974 meeting were the completed forms of work started at earlier conferences. The restricted distribution reports and memoranda represent initial ideas, problem suggestions, position papers, and status reports are aimed primarily to stimulate discussion within the Council and with its various consultants, and as such may not represent unanimous or majority opinions of the MRC. However, they are available by request to the Project Director subject to the author's release.

The breadth of activity of the Council during the 1974 conference can be seen from the following list of papers produced. Abstracts of many of these papers are given in the Appendix. In most cases where abstracts are not given, the full paper will appear as part of a subsequent report.

Summary of Discussions on Problems Relating to High Energy Laser Mirrors
N. Bloembergen

The Influence of Surface Layers and Inclusions on the Laser Induced Damage Threshold of Metal Mirrors
N. Bloembergen

Some Effects of Surface Structure on the Laser Induced Damage Threshold of Copper Mirrors
A. Bienenstock

Improvement of Diamond Machining Techniques
P. L. Richards

Comments on Fabrication, Fatigue Failure, and Hardening of Mirrors
J. J. Gilman

Determination of Tangential Roughness on Metal Surfaces by Surface Diffusion
H. Reiss

Evaporation Cooling of IR Mirrors
R. Gomer

Comments on the Surface Properties of IR Mirrors
R. Gomer

Infrared Absorptivity and Damage Thresholds of Metal Mirrors
M. Tinkham

UV Optical Properties of Oxide Coated Aluminum Mirrors
H. Ehrenreich

Scattering Measurements of Surface Roughness
W. H. Flygare

Influence of Dispersion Hardening on the Infrared Properties of Copper
A. J. Sievers

Electrons in Graded Crystal Lattices
W. Kohn

Comments on the Production of Hydrogen from Coal
M. F. Hawthorne

Materials Demand and Supply
R. M. Thomson

Critical Materials and Suggested DoD Issues
R. M. Thomson

Strategies of Materials Conservation
M. B. Bever

DoD Energy Requirements
W. Kohn and R. Gomer

Critical and Strategic Materials
M. J. Sinnott

Manganese as a Critical Material
M. Cohen

DoD Policy on Critical Materials
M. Cohen

Prospects of Nuclear Energy in Steelmaking
M. Cohen

Summary of Meeting on Conservation of Materials
R. M. Thomson and M. B. Bever

Outline for Studies of High Velocity Erosion
E. E. Hucke

Crater Formation and Erosion by Water Drop Impace
D. C. Drucker

Relationship Between Impact Yield Stress and Indentation Hardness
J. J. Gilman

Flow of Covalent Solids at Low Temperatures
J. J. Gilman

Flow Equations for Graphite
J. P. Hirth, E. E. Hucke and R. L. Coble

On the Mechanics of Erosion of Electromagnetic Windows by Rain
R. L. Coble

Opening the 3 to 5 Micron Window
M. F. Hawthorne

Meeting on Resistance to Rain Erosion by Electromagnetic Windows at Subsonic Speeds
R. L. Coble

A Meeting on Potentials for Plastic Processing of Brittle Ceramic Materials
R. L. Coble, J. J. Gilman, J. P. Hirth
F. A. McClintock and E. C. van Reuth

Summary of Meeting on Fundamentals of Forming of Brittle Polymers
A. S. Argon and M. B. Bever

Polymeric Entanglement Networks Cross-Linked in States of Strain
J. D. Ferry

Equilibrium Dispersion of Bulk Liquids
H. Reiss

Appraisal of Metal-Matrix Composites
M. B. Bever and P. E. Duwez

Summary of Meeting on the Status of Metal-Matrix Composites
M. B. Bever and P. E. Duwez

Theory of Overvoltage at Oxygen Electrodes Covered by a Thin Gas Film
R. A. Huggins and W. H. Flygare

Graded Density Flywheels
J. J. Gilman

Some Comments on the Shaped-Charge Problem
E. H. Lee and D. C. Drucker

On the Influence of Variations of Material Properties on Stress Wave Propagation Through Elastic Slabs
E. H. Lee, B. Budiansky and D. C. Drucker

Practical Aspects of High Energy Density Sodium-Sulfur Batteries with Beta Alumina Solid Electrolytes
R. A. Huggins

Degradation of Materials in Energy-Related Systems in the Presence of Hydrogen
J. P. Hirth and H. H. Johnson

Hydrogen and Corrosion Problems in Energy Related Technology
J. P. Hirth and H. H. Johnson

Some Mechanics Research Topics Related to the Hydrogen Embrittlement of Metals
J. [illegible] Rice

Hydrogen in Steel
A. Elsea

Availability of Coal for Gasification
H. W. Paxton

Critical Areas for Study
R. S. Treseder

Methane Nucleation at Alloy Carbides
H. W. Paxton

On the Availability of Adsorbable Gases in Crack Propagation
R. Gomer

The Influence of Hydrogen on Structural Alloys Which Readily Form Hydrides
H. G. Nelson

On Hydrogen Generation and Embrittlement Research
R. A. Oriani

On the Decohesion Theory of Hydrogen Embrittlement
R. A. Oriani

Hydrogen Embrittlement of Steel in Complex Gases
R. I. Jaffee

Hydrogen Effects in Structural Metals as Examples of Problems in the Development of Comprehensive Structural Integrity Technology
B. F. Brown

On Materials Use in Hydrogen
A. W. Thompson

Topics for Research Aimed At Understanding the Effects of Hydrogen on the Propagation of Cracks in Metals
R. W. Staehle

Nature of Corrosion in Geothermal Systems
R. S. Treseder

On the Use of Carbon Materials in Geothermal Systems
E. E. Hucke

Solar Energy Systems - Materials Problems
A. Bement, M. Cohen, H. Ehrenreich and R. Kaplow

Solar Energy Systems - Materials Problems Salient Points of Discussion Workshops
M. Cohen and H. Ehrenreich

Total Energy Community
G. W. Leonard

Overview of Heterojunctions and Novel Photovoltaic Devices
A. K. Ghosh

Photovoltaic Materials Problems
P. Rappaport

Material Science Aspects of Thin Film Systems for Solar Energy Conversion
B. O. Seraphin and A. B. Meinel

Solar Thermal Coatings
R. E. Peterson and H. Y. B. Mar

Spectral Properties of Small Particle Metallic Coatings II. Transition Metals
A. J. Sievers

A Technical Note on Transforming the Solar Spectrum with Selective Surfaces
A. J. Sievers

Fabrication of Low Cost Thin-Film Solar Cells
N. Laegreid, R. Wang and W. T. Pawlewicz

A Survey of the Options for the Commercial Production of Hydrogen as a Derived Fuel
R. A. Craig

The Heats of Formation of Transition Metal Hydrides and Energy Storage
H. Ehrenreich

Geothermal Corrosion Studies at the Naval Weapons Center
C. F. Austin and J. K. Pringle

Workshop on Solar Energy Systems
A. L. Bement

Workshops on Photovoltaics
R. Kaplow

A Discussion Summary: Thin Film Coatings for Photo-Thermal Conversion
A. J. Sievers and H. Ehrenreich

Workshop on Hydrogen in Energy Systems
M. F. Hawthorne

Visit to China Lake
M. Cohen

APPENDIX

GUEST CONSULTANT LIST

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ARPA MATERIALS RESEARCH COUNCIL
1974 GUEST CONSULTANT LIST

W. F. Adler
Bell Aerospace Company
P.O. Box 1, Mail Zone C86
Buffalo, New York 14240

T. Alfrey, Jr.
Dow Chemical Company
1702 Building
Midland, Michigan 48640

S. D. Allen
Hughes Research Laboratories
3011 Malibu Canyon Road
Malibu, California 90265

A. S. Argon
Room 1-312
Massachusetts Inst. of Tech.
Cambridge, Massachusetts 02139

C. F. Austin
Naval Weapons Center
Code 6033
China Lake, California 93555

J. M. Bennett
Naval Weapons Center
Code 6018, Michelson Lab.
China Lake, California 93555

H. E. Bennett
Naval Weapons Center
Code 6018, Michelson Lab.
China Lake, California 93555

A. Braunstein
Hughes Research Laboratories
3011 Malibu Canyon Road
Malibu, California 91307

M. Braunstein
Hughes Research Laboratories
3011 Malibu Canyon Road
Malibu, California 90265

B. F. Brown
Chemistry Department
American University
Washington, D.C. 20016

J. Bryan
Lawrence Livermore Laboratory
Mail Stop L-140
Livermore, California 94550

H. H. Caspers
Naval Electronics Lab. Ctr.
Bldg. 35, Room 13
San Diego, California 92152

W. T. Chandler
Rocketdyne, Rockwell Intl.
6633 Canoga Avenue
Canoga Park, California 91304

I. Cornet
6173 Etcheverry Hall
University of California
Berkeley, California 94720

R. A. Craig
Battelle Memorial Institute
505 King Avenue
Columbus, Ohio 43201

G. Daly
ERDO
4013 New Executive Ofc. Bldg.
Washington, D.C. 20006

A. R. Elsea
Battelle Columbus Labs.
505 King Avenue
Columbus, Ohio 43201

N. B. Elsner
Gulf General Atomic
L-346
La Jolla, California 92037

A. G. Evans
National Bureau of Standards
Inorganic Materials Bldg.
Gaithersburg, Maryland 20760

F. J. Fuchs
Western Electric
E. R. C.
Princeton, New Jersey 08540

A. G. Gaar
Naval Weapons Center
Code 5524
China Lake, California 93555

A. K. Ghosh
Exxon Res. & Eng. Co.
Room 3006, Bldg. 1
Linden, New Jersey 07036

A. J. Glass
Lawrence Livermore Laboratory
P.O. Box 808
Livermore, California 94550

W. F. Hall
Rockwell International
Science Center
Thousand Oaks, California 91360

J. C. Halpin
Air Force Materials Laboratory
Dayton, Ohio 45433

G. A. Hayes
U.S. Naval Weapons Center
Code 5585
China Lake, California 93555

M. K. Hubbert
U. S. Geological Survey
Mail Stop 922
Reston, Virginia 22092

E. Hughes
Stanford Research Institute
K-3023
Menlo Park, California 94025

R. I. Jaffee
Electric Power Research Inst.
3412 Hillview Avenue
Palo Alto, California 94304

H. H. Johnson
Cornell University
Bard Hall
Ithaca, New York 14850

F. R. Kalhammer
Electric Power Research Inst.
3412 Hillview Avenue
Palo Alto, California 94304

R. Kaplow
Room 13-5106
Massachusetts Inst. of Tech.
Cambridge, Massachusetts 02139

E. G. Kendall
Aerospace Corporation
130/422
Los Angeles, California

N. Laegreid
Battelle Northwest Labs.
231-2 Bldg. 200 W.
Richland, Washington 99352

G. W. Leonard
Naval Weapons Center
Code 45
China Lake, California 93555

M. Levine
Stanford Research Institute
K-3024
Menlo Park, California 94025

C. F. Markarian
Naval Weapons Center
Rm. 2057, Michelson Lab.
China Lake, California 93555

A. B. Meinel
Optical Sciences Center
University of Arizona
Tucson, Arizona 85721

A. S. Metcalfe
Solar Division
International Harvester Co.
2200 Pacific Highway
San Diego, California 92138

H. G. Nelson
Ames Research Center
240-1
Moffett Field, Calif. 94022

R. A. Oriani
U.S. Steel Corporation
Mail Stop 98
Monroeville, Pennsylvania 15146

H. W. Paxton
Carnegie Mellon Institute
of Research
4400 Fifth Avenue
Pittsburgh, Pennsylvania 15213

A. Peterlin
National Bureau of Standards
A323, Polymer Bldg.
Washington, D.C. 20234

R. E. Peterson
Honeywell Inc.
2600 Ridgeway Parkway
Mail Station R2340
Minneapolis, Minnesota

K. M. Prewo
United Aircraft Research Labs.
E. Hartford, Connecticut 06040

P. Rappaport
RCA Laboratories
Princeton, New Jersey 08540

H. E. Rast
Naval Electronics Lab. Center
Code 2600
San Diego, California 92152

W. H. Reichelt
Los Alamos Science Center
Los Alamos, New Mexico 87544

D. K. Rice
Northrop Res. & Tech. Center
3401 W. Broadway
Hawthorne, California

S. Ruby
Advanced Res. Projects Agency
1400 Wilson Avenue
Washington, D.C. 22209

T. T. Saito
Air Force Weapons Laboratory
AFWL-LRE
Kirtland AFB, New Mexico 87117

J. A. Sauer
Rutgers University
Dept. Mechanics & Materials Sci.
New Brunswick, New Jersey 08903

D. G. Schueler
Sandia Laboratory
Division 5113
Albuquerque, New Mexico 87115

D. M. Schuster
Sandia Laboratories
Dept. 5840
Albuquerque, New Mexido 87110

F. Seitz
Rockefeller University
1230 Yale Avenue
New York, New York

J. R. M. Seitz
Harvard University
Gordon McKay 405
Cambridge, Massachusetts 02138

J. C. Shyne
Stanford University
Materials Sci. & Eng. Dept.
Stanford, California 94305

T. L. Smith
IBM Research Laboratory
K42/282
San Jose, California

M. Sparks
Xonics Inc.
6837 Hayvenhurst Avenue
Van Nuys, California 91406

W. J. Spawr
Spawr Optical Research
130 N. Sherman Avenue
Corona, California 91720

D. F. Spencer
Electric Power Res. Inst.
3412 Hillview Avenue
Palo Alto, California 94304

B. Springer
Rand Corporation
1700 Main Street
Santa Monica, California

R. W. Staehle
Ohio State University
Dept. of Metallurgical Eng.
Columbus, Ohio 43210

S. S. Sternstein
Materials Division
Rensselaer Polytechnic Inst.
Troy, New York 12180

C. M. Stickley
Advanced Res. Projects Agency
1400 Wilson Boulevard
Washington, D.C. 22209

R. P. Stromberg
Solar Energy Systems Div. 5717
Sandia Laboratories
Albuquerque, New Mexico 87115

A. W. Thompson
Rockwell International
Science Center
Thousand Oaks, California 91360

R. S. Treseder
6272 Girvin Drive
Oakland, California 94611

E. C. van Reuth
Advanced Res. Projects Agency
1400 Wilson Boulevard
Arlington, Virginia 22209

V. Wang
Hughes Research Laboratory
3011 Malibu Canyon Road
Malibu, California 90265

M. D. Weisinger
General Dynamics Convair
Dept. 119-00
San Diego, California 92112

C. A. Wert
National Science Foundation
Room 336, DMR
1800 G Street
Washington, D.C. 20550

T. Wolfram
University of Missouri
Physics 223
Columbia, Missouri 65301

APPENDIX

ABSTRACTS

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THE INFLUENCE OF SURFACE LAYERS AND INCLUSIONS ON THE LASER INDUCED DAMAGE THRESHOLD OF METAL MIRRORS

N. Bloembergen

ABSTRACT

A survey is given of the physical mechanisms that determine the damage threshold of metallic reflecting surfaces in the infrared. The important role of thermal contact of the surface layer with the bulk is emphasized. The variation of surface conductivity with structure of the surface layer and with temperature, and its correlation with surface roughness, is discussed.

SOME EFFECTS OF SURFACE STRUCTURE ON THE LASER INDUCED DAMAGE THRESHOLD OF COPPER MIRRORS

A. Bienenstock

ABSTRACT

It is proposed that the excess surface absorption of 10.6 micron laser radiation by Cu mirrors is caused by the small crystallites and resulting small electron mean free paths. This hypothesis is correlated with experimental studies of absorption and damage threshold. Apparently contradictory experimental results for Ag and Au evaporated mirrors are rationalized in terms of hypothesized different film growth structures of these metals. In addition, the melting model of breakdown threshold is examined in light of existing experimental results. It is shown that it is extremely unlikely that some mirrors reached the melting temperature at breakdown, whereas others were likely to have exceeded it. The "paving-over" model is also discussed. It appears to be inconsistent with modern pictures of polishing. The analysis of the absorption and breakdown threshold models suggests that: (a) careful, weak etches of superpolished mirrors may yield low absorptions and high thresholds without destroying the optical figure; (b) rms roughness is an insufficient surface characterization tool; (c) electron diffraction and taper-sectioning are more likely to yield the surface characterizations which will lead to improved mirror performance; (d) understanding of the breakdown is quite limited.

IMPROVEMENT OF DIAMOND MACHINING TECHNIQUES

P. L. Richards

ABSTRACT

The finish of diamond machined surfaces is presently limited by low frequency vibrations which vary the separation between the tool and the average surface of the work. A procedure for improving this surface finish is suggested which makes use of a capacitive technique to measure the distance between the tool and the work surface, and feedback to a piezo-electric tool holder to maintain the distance constant. In its simplest form, the technique can be tested by an inexpensive modification of an existing lathe of the type used for diamond turning. The technique can be used for curved surfaces if the tool angle is controlled as the surface is finished. The possibility exists of making relatively inexpensive diamond finishing machines to be used for improving the finish on surfaces which were previously figured by other means.

COMMENTS ON FABRICATION, FATIGUE FAILURE, AND HARDENING OF MIRRORS

J. J. Gilman

ABSTRACT

The following three topics are briefly discussed:

a. Technique for making metallic mirrors with damage-free surfaces.

b. Degradation of mirrors under repetitive optical loading because of mechanical "fatigue".

c. Mechanical hardening of mirrors by radiation damage.

DETERMINATION OF TANGENTIAL ROUGHNESS
ON METAL SURFACES BY SURFACE DIFFUSION

H. Reiss

ABSTRACT

It is a relatively easy matter to determine, by optical means, the RMS "roughness" normal to a polished metal surface. On the other hand it is difficult to measure nonuniformities of wavelength approximating atomic and molecular dimensions tangential to the surface. A method is suggested for obtaining information in this respect, based on the diffusion of molecules like stearic acid across the surface.

The method involves the transfer of a compressed, "crystallized" monolayer of stearic acid from a Langmuir trough to part of the metal surface. The transferred layer will retain its order and "bridge" surface irregularities of small wavelength. The diffusion from this ordered layer over uncovered regions of the surface is then studied, possibly through the use of ellipsometry. The diffusing molecules will actually follow the true contour of the surface. A combination of the known "bridged" ordering of the original layer and the fact that the diffusing molecules follow the true contour allows information about the tangential roughness to be obtained from the observed diffusion rate.

EVAPORATION COOLING OF IR MIRRORS

R. Gomer

ABSTRACT

The feasibility of cooling IR mirrors subject to intense laser pulses by flash evaporation of thin non-absorbing layers is discussed, and it is shown that this method should work. Specific examples are worked out in some detail and limiting parameters are discussed.

COMMENTS ON THE SURFACE PROPERTIES OF IR MIRRORS

R. Gomer

ABSTRACT

Some techniques for examining mirror surfaces and substrates and some possible uses they might be put to are briefly discussed.

INFRARED ABSORPTIVITY AND DAMAGE THRESHOLDS OF METAL MIRRORS

M. Tinkham

ABSTRACT

The infrared absorptivity A of metal mirrors is calculated as a function of electron mean free path, ℓ, i.e., of temperature and purity. This is done for both specular and diffuse electron scattering at an ideal planar surface (see Fig. 1), for a thin surface layer of higher resistivity than the bulk, and (qualitatively) for the case of geometrically limited free paths in a microscopically rough surface. The results (for copper, as a numerical example) at room temperature are typically $A \approx 0.5\%$ for specular scattering at an ideal surface, $A \approx 0.8\%$ for diffuse scattering, $A \approx 1.4\%$ for a 90Å layer with $\ell_s = 60\text{Å} = \ell/7$, and $A/A_{ideal} \approx 1 + \sigma/(15\text{Å})$ for an rms surface roughness σ with short ($\sim 100\text{Å}$) lateral range scale. At the melting point T_M, even an ideal surface is estimated to have $A \approx 2.5\%$ for the solid and $A \approx 4\%$ for the liquid phase. Because of the sharp increase of A with heating and upon melting, the total incident fluence required to reach T_M is relatively insensitive to the initial (room temperature) value of A, or to the damage threshold criterion used; but it will be sensitive to the thermal diffusivity and integrity of the

material. For ideal copper surfaces, and a 0.6 microsecond square pulse, we estimate $\sim$215 J/cm^2 if the threshold criterion is melting, and $\sim$320 J/cm^2 if it is the start of vaporization. For the actual shape of the nominal 0.6 microsecond pulses of the Hughes work, these theoretical values would be roughly doubled. These doubled estimates give quite a good account of the highest experimental values found, even including the anomalously high ($\sim$750 J/cm^2) value reported for the case of a focal spot small enough to bring into question the one-dimensional heat flow condition used here. Thus, the best present mirrors must be very near the theoretical limit.

UV OPTICAL PROPERTIES OF OXIDE COATED ALUMINUM FILMS

H. Ehrenreich

ABSTRACT

The reflectance of oxidized aluminum films is known to fall off rapidly for photon energies greater than about 6 eV. For non-oxidized films, on the other hand, the reflectance retains a value greater than .85 up to 13 eV. The behavior of the oxidized films in the 6-13 eV region has been puzzling, since the oxide layers are generally no more than 50-100A thick. A semi-quantitative explanation of the observed features is presented on the basis of a 50-100A uniformly thick "amorphous" aluminum layer on pure aluminum. The effects are due both to interference and absorption in the Al_2O_3. Thus, thin films can be extremely deleterious to laser mirror performance in the ultraviolet. In the infrared, on the other hand, their presence is far less significant, except at very high laser powers.

SCATTERING MEASUREMENTS OF SURFACE ROUGHNESS

W. H. Flygare

ABSTRACT

It is probable that surface roughness down to a 10Å scale is important in the absorption process during high power 10.6μ laser radiation on reflecting mirrors. This note summarizes the theory and experimental methods of low angle X-ray scattering to examine surface roughness. We suggest that these methods of low angle X-ray scattering be used in place of the Fabry-Perot method of using fringes of equal chromatic order (FECO) which has a very good vertical resolution (perpendicular to the surface) but very poor horizontal resolution (on the order of the radiation wavelength). Experimental work on low-angle X-ray scattering appears to give the needed information on roughness and we suggest a correlation of the surface X-ray coherence length with absorption in order to understand the mechanisms of radiation absorption on mirrors.

INFLUENCE OF DISPERSION HARDENING ON THE INFRARED PROPERTIES OF COPPER

A. J. Sievers

ABSTRACT

We show that the introduction of submicroscopic dielectric particles into a metal such as copper changes the optical properties of the metal from those represented by a simple plasma to those of a plasma plus discrete electronic transitions. The past procedure of neglecting the composite nature of the medium and approximating it by a simple Drude contribution leads to an incorrect assessment of the electron plasma relaxation time and an overestimate of the infrared absorption at 10μ associated with the real material. The correction factor is estimated.

ELECTRONS IN GRADED CRYSTAL LATTICES

W. Kohn

ABSTRACT

This paper contributes to the theory of the dynamics of electrons in a crystal lattice with a gently graded, quasi-periodic potential. By means of a unitary transformation the effective quantum mechanical Hamiltonian operator $E(p,r)$ is derived a priori, where $E(k,r)$, for fixed r, is the band structure near the point r. The motion of wave-packets is controlled by Hamilton's equations $\dot{r} = \nabla_k E(k,r)$, $\dot{k} = -\nabla_r E(k,r)$. Electronic transport current is given by $J_n(r) = -qn(r)\bar{\mu}(r) \nabla\phi_n(r)$, where $\phi_n(r)$ is the quasi Fermi level defined in analogy with Shockley's definition for the case of p-n homojunctions.

COMMENTS ON THE PRODUCTION OF
HYDROGEN FROM COAL

M. F. Hawthorne

ABSTRACT

The suggestion is made that the use of coal to generate hydrogen really does not solve an energy problem since the hydrogen produced must be transported through now non-existent high pressure gas lines. A more practical solution would involve the conversion of coal to methane or methanol. These fuels are compatible with existing pipelines.

MATERIALS DEMAND AND SUPPLY

R. M. Thomson

ABSTRACT

Materials availability and resource prediction are reviewed for a number of non fuel resources in the light of Hubbert's analysis of resource limits, and the world models of Forrester and Meadows. Non fuel resources are far more complex to analyze than fuel resources; they are complicated by prospects for recycling and by the unpredictability of technological advance. Methods for modeling the system are proposed and factors important to this analysis are discussed.

CRITICAL MATERIALS AND SUGGESTED DOD ISSUES

R. Thomson

ABSTRACT

The issues involved in critical materials shortages is reviewed relative to the DoD. It is concluded that DoD should take an aggressive role in studies of how critical materials can be used as a weapon in national emergencies, and in technical solutions to the problems which supply cut-off would cause. Possible ARPA activities lie in 1) studies of critical materials vulnerability, 2) techniques exploration and processing, 3) materials substitution, and 4) recycling possibilities. Molybdenum is suggested for special attention as a candidate superalloy, but rapid oxidation at high temperature is a technical challenge.

STRATEGIES OF MATERIALS CONSERVATION

M. B. Bever

ABSTRACT

Efficient utilization, substitution and recycling are the main strategies for the conservation of materials. These strategies can interact with each other and call for a systems approach. They also have environmental and energy implications which for recycling are usually favorable. The contributions to conservation to be expected from more efficient utilization, substitution and recycling of materials can be assessed. These strategies are promoted to some extent by economic forces, but favorable public attitudes and appropriate policies are also required.

DOD ENERGY REQUIREMENTS

W. Kohn and R. Gomer

ABSTRACT

It is remarked that while the direct energy consumption of the DoD is approximately equal to 2.4% of the total U.S. consumption, the total energy consumption of the DoD is in the neighborhood of 6.3% or more. Implications, particularly for DoD supported R and D, are briefly discussed.

CRATER FORMATION AND EROSION
BY WATER DROP IMPACT

D. C. Drucker

ABSTRACT

A simplified description in the spirit of Goodier and Donaldson is given of the effect of high velocity normal impact of a water drop or other particle on the flat surface of a semi-infinite target. Depth of penetration and crater formation for a ductile target are related directly to the kinetic energy transmitted to (deposited on) the target in the region of the crater.

A brittle or friable target traversing a cloud of water drops suffers enormously greater damage than a ductile one of the same strength. Much of the highly compressed and now granular zone surrounding the crater as it is formed will be lost on rebound or on subsequent impact at neighboring points of the surface by the smaller as well as larger particles. The diameter of this zone is several times the crater diameter, a ratio as low as 2x would give a mass loss of 8x that otherwise would be expected.

The variables which govern the volume of the crater formed in the loading stage are very different in three ranges

of impact speed v_p because the efficiency of energy transfer to the target goes from a low to a high value. At moderate to intermediate speeds including the range close to C_p, the speed of dilatational waves in water, and below 1/2 of C_t, the speed of dilatational waves in the target, the ratio of crater volume to volume of the drop is given approximately by

$$\left(\frac{\frac{1}{2}\rho_p v_p^{\,2}}{\sigma_t}\right)\left(\frac{\rho_p v_p^{\,2}}{\rho_t C_t^{\,2}}\right) \quad .$$

ρ_p, ρ_t are the mass densities of drop and target respectively, $\rho_t C_t^{\,2} = E_t$ the elastic modulus for uniaxial <u>strain</u>, and σ_t (about 4x the flow stress at strains of order unity) is the punching out or spherical expansion yield or limit stress as used by Goodier. The kinetic energy ratio $\rho_p v_p^{\,2}/\rho_t C_t^{\,2}$ or $\rho_p v_p^{\,2}/E_t$ is small below v_p/C_t of one half. At hypervelocity impact speeds to several times C_t, 1/3 to 1/2 of the kinetic energy of impacting drop is transferred to a rather shallow region of the target and $\frac{1}{4}\rho_p v_p^{\,2}/\sigma_t$ gives the ratio of the crater volume to the volume of the drop. In the transition range from v_p/C_t of less than 1/2 to more than unity, the kinetic energy ratio goes over smoothly from $\rho_p v_p^{\,2}/\rho_t C_t^{\,2}$ to virtual independence of target density and impact speed.

The $v_p^{\,4}$ variation at moderate speeds is in encouraging agreement with experiment as is the transition to the simple energy form $\frac{1}{2}(\frac{1}{2}\rho_p v_p^{\,2})/\sigma_t$ much as proposed explicitly by Feldman, Eichelberger and Gehring in terms of Brinell hardness and com-

puted by Goodier.

Rod impact (plane stress) and plate impact (plane strain) with water as the impactor serve as one-dimensional examples to set the stage for the discussion of a drop impacting on a surface. They exhibit both the plausibility and the limitations of the analysis based primarily on spherical symmetry.

RELATIONSHIP BETWEEN IMPACT YIELD STRESS AND INDENTATION HARDNESS

J. J. Gilman

ABSTRACT

Impact yield stresses for hard, brittle substances can be related quantitatively to indentation hardnesses if it is assumed that both are governed by a critical shear stress criterion for the onset of rapid plastic flow. The critical shear stress τ_{gp} is related to the shear stiffness on the glide plane by:

$$\tau_{gp} \simeq 0.043\ G_{gp}$$

Therefore, hardness measurements can be used to obtain low temperature yield stresses for these materials; and to estimate impact yield stresses.

FLOW OF COVALENT SOLIDS AT LOW TEMPERATURES

J. J. Gilman

ABSTRACT

An empirical correlation shows that the activation energy for plastic flow in covalent solids equals twice the energy gap. This provides evidence that the flow rate is controlled by the rate of tunneling of bonding electrons into anti-bonding states under the influence of the applied stress. This model yields an explicit expression for the critical shear stress that contains no adjustable parameters and which agrees quantitatively with observations.

At finite temperatures tunneling is assisted by high frequency phonons. An explicit equation for the temperature dependence is derived that contains no disposable parameters and which conforms quite well with observations.

FLOW EQUATIONS FOR GRAPHITE

J. P. Hirth, E. E. Hucke and R. Coble

ABSTRACT

In analyzing erosion of graphite at high strain rate ($\sim 10^7$ sec^{-1}) and temperature ($\sim 4000°C$), it is necessary to have some approximation for the constituitive equation. Data for graphite from static and low strain rate experiments were successfully correlated using the equation:

$$\frac{\dot{\varepsilon} kT}{DbG} = c' \left(\frac{\sigma}{G}\right)^n$$

which describes the flow of many metals and crystalline ceramics. In this equation, $\dot{\varepsilon}$ is the strain rate, k is Boltzmann's constant, D is the self diffusivity, b is the dislocation Burgers vector, G the shear modulus. T absolute temperature, σ the resolved shear stress, and n is a constant equal to 8 for graphite. Solution of the above equation for several specific cases of interest in hypersonic rain erosion at high temperature gives values for flow stress of from 2 to 10 Kbar. Changes in temperature of about 500°C or strain rate by a factor 100 shift this value by more than 50%.

ON THE MECHANICS OR EROSION
OF ELECTROMAGNETIC WINDOWS BY RAIN

R. L. Coble

ABSTRACT

Following the MRC Meeting on Rain Erosion Resistance, the literature on subsonic liquid-solid impacts was reviewed. The factors of interest are the dynamics of interaction between liquid droplets and solid substrates - what are the pressure distributions? What is the time of duration of impact, how does the target respond and what are the potential modes of failure in such targets?

It was concluded that for low velocity impact, the response of the target can be roughly approximated by the Hertz-Huber solution: that for the elastic displacements that occur under a static load. However, the peak stresses which develop are sensitively dependent upon the pressure distribution in the contact zone. Since the review shows that there is considerable uncertainty as to what the pressure distribution is, the peak pressures and the magnitudes, durations and distribution of stresses near the peak tensile stress areas are not known with sufficient accuracy to utilize this model to predict when fracture should occur.

Slow crack growth, as documented in numerous glasses and ceramics, varies as a power function of the stress intensity factor: $\dot{C} + AK^n$, where n may be 20 or greater. The importance of the slow crack growth regime is that electromagnetic windows must be subjected to billions of rain drop impacts while the flaws initially present must not propagate to dimensions that would cause considerable light scattering or ultimate failure. Because of the high value of the exponent on stress for slow crack growth, it is the peak tensile stresses and the volume within which those arise that are most important in governing failure. In the absence of being able to predict the service life at the present time, there is a need for experimental determination of the incubation times to first observable damage (crack or flaw propagation) as a function of the impact velocity. The threshold velocity should be correlated with documentation of the flaw distributions determined by static indents using hard indentors.

Because of the rapid decrease in peak tensile stresses in a position away from the site of impact in a Hertzian model and the fact that the initial flaw sizes are small, it seems likely that thin hard coatings could afford significant improvement in rain erosion resistance for inferior candidate substrates.

Soft elastomeric coatings also have been shown to give a surprising resistance to rain erosion and also have the advantage of being repairable after exposure in service. There-

fore, improvement in available elastomeric materials with transparency at longer wave lengths (3-5 microns) than those now available, should be pursued in a development effort on carbon-deuterium polymers. These materials would give transparency out into the wavelength region of interest for heat-seeking missiles, and be applicable to radomes as well.

OPENING THE 3 TO 5 MICRON WINDOW

M. F. Hawthorne

ABSTRACT

The degradation of optical surfaces in infrared optical devices flown by high performance aircraft might be alleviated by using transparent organic polymer coatings. It is suggested that such coatings could be made transparent in the 3 to 5μ region by incorporating C-D bonds for all (or nearly all) C-H bonds in the polymer. No degradation in physical properties should result and the infrared absorption of C-H stretching modes near 3.5μ would be removed.

A MEETING ON POTENTIALS FOR PLASTIC PROCESSING OF BRITTLE CERAMIC MATERIALS

R. L. Coble, J. J. Gilman, J. P. Hirth,
F. A. McClintock and E. C. van Reuth

ABSTRACT

The techniques which have been studied in past efforts to process ceramics plastically was reviewed with particular emphasis on needs for improved windows for high power infrared lasers. Greater amounts of retained cold work or cell size reduction, or both, in solution hardened materials is required. It was concluded that the best prospect for achieving these goals while avoiding fracture is to isotatically extrude the billets into a window shaped cavity.

POLYMERIC ENTANGLEMENT NETWORKS CROSS-LINKED IN STATES OF STRAIN

J. D. Ferry

ABSTRACT

The properties of networks formed by cross-linking amorphous entangled polymers in states of strain have been further examined. A hypothesis of O. Kramer that the strain energy associated with the entanglements is proportional to the second strain invariant whereas that associated with the cross-links is proportional to the first strain invariant has been used to calculate states of ease, stress-strain relations in simple extension, and Young's moduli parallel and perpendicular to the original stretch direction. An earlier calculation of the kinetics of approach to the state of ease is reviewed and a preliminary comparison with experiment is made.

EQUILIBRIUM DISPERSION OF BULK LIQUIDS

H. Reiss

ABSTRACT

The dispersion of a bulk liquid within a vapor phase or within another liquid phase (emulsion) occasions an increase in surface free energy. If this were the only change in free energy, such a dispersed state could never represent a thermodynamic equilibrium condition. On the other hand a decrease in free energy (usually small) also occurs in view of the "entropy of mixing" the dispersed phase with the surrounding phase. If the interfacial tension between the two phases can be suitably reduced, this decrease may be enough to counterbalance the above-mentioned increase, and spontaneous dispersion may occur. Such spontaneous dispersion may be of technological importance in cloud dispersal (for example, to reduce erosion on air frames, or to functionlize airports) or in the recovery of oil in the tertiary phase.

The possibility of such spontaneous dispersion, with the aid of a surfactant, is investigated theoretically (semi-quantitatively) by means of statistical mechanics. It is concluded that there is little hope of dispersing clouds because of the low mass loading of the air by water (leading to small

mixing entropies) and because surfactants are unable to produce sufficiently low surface tensions. However, it may be possible to cause spontaneous emulsification of oil in water if the interfacial free energy can be reduced to 10^{-4} dynes/cm, a value which has already been achieved by certain surfactants.

APPRAISAL OF METAL-MATRIX COMPOSITES

M. B. Bever and P. E. Duwez

ABSTRACT

In this memorandum we review the status and potential of metal-matrix composites against the background of our memorandum of 1970. We find a growing number of successful applications and an associated shift in emphasis from laboratory research to engineering development. The decrease in the costs of metal-matrix composites is affecting their competitive position relative to polymer-matrix composites and other materials; performance characteristics, therefore, are no longer the sole criteria for adoption of metal-matrix composites.

The memorandum reviews possible combinations of matrix metals and available filaments and rates the usefulness of these combinations, in several cases changing the ratings in our earlier memorandum. Structural variables are briefly considered. Special attention is given to new methods of fabrication and to production costs. Limitations in the use of metal-matrix composites are considered. Several applications are briefly described.

THEORY OF OVERVOLTAGE AT OXYGEN ELECTRODES COVERED BY A THIN GAS FILM

R. A. Huggins and W. H. Flygare

ABSTRACT

One of the major drawbacks in the direct electrolysis of water to give H_2 and O_2, is the overvoltage at the oxygen electrode. This requires a higher cell voltage and resultant lower efficiency. We have examined a plausible model for the overvoltage at the oxygen electrode based on the impedance to electron transfer at high current density due to the existance of a layer of O_2 gas at the electrode. It is shown that the overvoltage from this source is proportional to the logarithm of the electrode current. Several suggestions are presented for influencing the presence of the gaseous O_2 layer, leading to a decrease in the overvoltage problem.

GRADED DENSITY FLYWHEELS

J. J. Gilman

ABSTRACT

Grading the density of a tape-disk flywheel can improve its specific volume efficiency up to a factor of two. Grading decreases its specific weight efficiency. The efficiencies for a variety of flywheel designs are summarized.

SOME COMMENTS ON THE SHAPED-CHARGE PROBLEM

E. H. Lee and D. C. Drucker

ABSTRACT

The question of the feasibility of finite-element calculations of the collapse of a shaped-charge as an aid in design development is addressed. It is pointed out that a simple approach, which treats the liner and jet as a fluid, provides a helpful approximation which should be used in parallel with whatever more elaborate calculations are carried out. The challenge of evaluation of the process by a finite element calculation is a formidable one because of (i) the open form of the material configuration with narrow cross-sections and extensive free surfaces, (ii) the material deformation regimes of very large strains developed at high rates, (iii) the high temperatures generated and (iv) the possible importance of jet fracture on the penetration process. Comments on the bearing of this assessment on the planning of a development program are presented.

ON THE INFLUENCE OF VARIATIONS OF MATERIAL PROPERTIES ON STRESS WAVE PROPAGATION THROUGH ELASTIC SLABS

E. H. Lee, B. Budiansky and D. C. Drucker

ABSTRACT

The influence of variation of elastic properties through a plate on the propagation of elastic waves through it has been studied, with a view to investigating its ability to withstand impact. The relative merit of properties changes in a series of steps (graded material) or continuous variation (gradient material) is investigated.

It is found that for an elastic slab with elastic modulus increasing continuously with depth, the magnitude of the stress wave front associated with an applied discontinuous surface pressure varies in proportion to $\sqrt{\rho(x)c(x)}$ where ρ is the density and c the elastic wave speed for dilatational waves. This magnitude grows indefinitely with increasing $c(x)$. However, it is known that in the limit of a sudden change of properties as at an interface with a rigid body ($c \to \infty$), the stress magnitude only doubles. This paradox is explained by noting a singular approach to the limit of the continuously varying case. A boundary layer consisting of a peak of high stress can occur for sharp changes of properties, which narrows as the gradient material approaches a graded one. The possible significance of this result to material damage under dynamic loading is discussed.

PRACTICAL ASPECTS OF HIGH ENERGY DENSITY SODIUM-SULFUR BATTERIES WITH BETA ALUMINA SOLID ELECTROLYTES

R. A. Huggins

ABSTRACT

One of the new high performance rechargeable battery systems presently getting substantial development attention involves the so-called sodium-sulfur cell. This system, which operates at elevated temperatures, utilizes a sodium ion-conducting solid ceramic electrolyte of beta alumina and liquid sodium and polysulfide electrodes.

This paper discusses a number of the practical aspects of sodium-sulfur cells, and where the important technological problems lie.

SOME MECHANICS RESEARCH TOPICS RELATED TO THE HYDROGEN EMBRITTLEMENT OF METALS

J. R. Rice

ABSTRACT

The report suggests some research studies on the mechanics of fracture which should lead to a better understanding of the mechanisms of hydrogen embrittlement of metals, notably steels. The topics suggested include: studies of critical stress levels for initiation of H cracking, as a function of local H concentration, and estimates of the required size scale over which they must prevail for continual growth into the steep stress gradients ahead of a macroscopic crack; determination of the H-altered cohesive strength of material interfaces in relation to fracture nucleation and growth processes; study of the effect of H on plastic flow at a crack tip and in ductile rupture cavity growth; coupling of triaxial stress, plastic strain and strain rate with H entry at deforming surfaces, H transport by diffusion, and equilibrium H concentrations; and processes of pressurized gas formation in rupture cavities and its role in their growth to terminal coalescence.

ON THE AVAILABILITY OF ADSORBABLE GASES IN CRACK PROPAGATION

R. Gomer

ABSTRACT

The possible contribution of adsorbed gas to crack propagation is examined from the point of view of speed of adsorption and diffusion of active gas through an inert atmosphere to the crack. It is concluded that gas at 0.2 atmospheres can adsorb with sufficient speed for crack propagation velocities of ≤ 3 cm/sec, and can diffuse with sufficient rapidity through an inert medium at 1 atm. pressure if $10^3 \sin\theta \gg$ crack velocity.

SPECTRAL PROPERTIES OF SMALL PARTICLE
METALLIC COATINGS
II. TRANSITION METALS

A. J. Sievers

ABSTRACT

The lowest frequency near-resonance of small (~100Å) particles of transition elements in dielectric composite structures can be adjusted to occur in the center of the solar spectrum by controlling the density of the particles, the medium in which the particles are embedded and/or the composite layer thickness. These particulate metal coatings on a low emissivity copper surface should provide the necessary temperature independent frequency selectivity for a solar collector.

THE HEATS OF FORMATION OF TRANSITION METAL HYDRIDES AND ENERGY STORAGE

H. Ehrenreich

ABSTRACT

In view of recent interest in metal hydrides as a useful energy source and storage medium, it is of importance to understand the systematics of the heats of formation for the 3d and 4d transition metals and their alloys. A search for optimum transition metal alloys would be facilitated by an understanding of principal sources giving rise to the heat of formation. Preliminary calculations reported in this paper indicate that these are: (1) the formation of a bonding metal-hydrogen band below the pure metal conduction band minimum; (2) a lowering of the d bands; and (3) the binding of the additional electron associated with each hydrogen atom at the top of the Fermi distribution. Detailed calculations for Ti, Ni, Cu, and Pd hydrides suggest an empirical formula that delineates the magnitude of these contributions. Its application to other hydrides of the 3d and 4d rows indicate that the systematic trends can be explained. Applications to alloy hydrides, such as TiFe studied by Wiswall and collaborators at Brookhaven, have not yet been undertaken, but are probably feasible within the present theoretical framework.

APPENDIX

MEETING SUMMARIES

SUMMARY OF DISCUSSIONS ON PROBLEMS RELATING TO HIGH ENERGY LASER MIRRORS

N. Bloembergen

ABSTRACT

Approximately twenty outside users and developers met with members of the Council to discuss problems relating to laser mirrors, capable of withstanding high energy fluence.

The oral presentations were concerned with:

a) Basic optical properties and absorption by metals of infrared radiation

b) Damage mechanisms

c) Fabrication techniques of metallic mirrors

d) Characteristics of optical properties and damage thresholds

The program of the presentation was as follows:

N. Bloembergen (MRC), Introduction to Damage Problems

M. Sparks (Xonics Corporation), Damage by Laser Heating of Metal Mirrors

H. E. Bennett (NWC Michelson Laboratory), Optical Requirements for High Energy Laser Mirrors

J. M. Bennett (NWC Michelson Laboratory), Statistical Characterization of Mirror Surfaces

W. H. Reichelt (Los Alamos Scientific Laboratory), Diamond Tool Machining of Mirrors and Damage Thresholds for Nanosecond Pulses

J. B. Bryan (Lawrence Livermore Laboratory), Diamond Tool Machining Techniques for Laser Mirrors

H. Ehrenreich (MRC), Review of Optical Absorption by Metals

T. T. Saito (AFWL Kirtland), 10.6μm cω Laser Damage Studies of Metal Substrate Mirrors

M. Braunstein, A. Braunstein, V. Wang, and S. D. Allen (Hughes Research Laboratories), Pulsed CO_2 Laser Damage Studies of Reflectors, Windows, and Coatings

D. Rice (Northrup), Laser Mirrors and Materials for 3.5μm Wavelength

N. Laegried (Battelle Northwest Laboratories), Sputtering Techniques for Metal Mirrors

J. Spawn (Spawn Optical), Visual Inspection of IR Mirrors

A. J. Glass (Lawrence Livermore Laboratory), Summary of Conference

The very useful summary of the meeting written by Alex Glass is reproduced in full as an Appendix to the Summary Report.

The meeting was followed by a conference on IR window erosion, where some damage problems related to dielectric coatings and window materials were discussed. These meetings provided a starting point for further studies and deliberations by members of the MRC.

SUMMARY OF MEETING ON CONSERVATION OF MATERIALS

R. M. Thomson and M. B. Bever

ABSTRACT

A one-day meeting on materials conservation is summarized. Four general presentations dealt with the U.S. position in raw materials and several strategies of conservation. The prospects for materials supplies were discussed from the viewpoints of geology, economics and technology. Two presentations addressed the more immediate strategic issues of materials scarcities. Reasons for concern on the part of ARPA became apparent and the entire subject deserves continuing attention.

MEETING ON RESISTANCE TO RAIN EROSION BY ELECTROMAGNETIC WINDOWS AT SUBSONIC SPEEDS

R. L. Coble

ABSTRACT

The state of the art in the fabrication, characterization and performance of the various electromagnetic window material resistance to rain erosion is summarized. At the end of the MRC meeting several tentative conclusions were drawn.

1. Single crystal sapphire should be utilized for the infrared heat seeking missiles (3-5 microns), since it has empirically exhibited greater resistance to rain erosion than do the materials (M_gF_2) now utilized in service.

2. Improved elastomeric coatings are needed for protection of radomes and IR windows fabricated from bulk polymers, reinforced polymers and ceramics. Transmission to longer wave lengths and higher temperature resistance are needed.

3. It was concluded that the development of techniques for growth of crystals of diamond for potential use in high power infrared lasers was justified because of the clearly superior properties which diamond exhibits for this application.

4. It was tentatively concluded that the resistance to rain erosion of brittle materials is best correlated with the

hardness of the materials or with the critical stress intensity factor for fracture (K_{IC}). Hence materials selection should be based on K_{IC} and efforts for improvement of existing materials should be focused on this characteristic.

SUMMARY OF MEETING ON
FUNDAMENTALS OF FORMING OF BRITTLE POLYMERS

A. S. Argon and M. B. Bever

ABSTRACT

This memorandum summarizes a two-day meeting on the forming of polymers with special emphasis on the forming of brittle or intractable polymers. The latter are mostly thermosetting plastics which tend to decompose before softening upon heating.

In the opening session several presentations provided the fundamental background on the deformation of polymers. The core of the program was concerned with the mechanical processing of polymers and especially brittle or intractable polymers. Various promising techniques which lend themselves to this task were considered. In the final session, the mechanical behavior of elastomers and polymeric composites was reviewed. The general discussions were largely concerned with brittleness and ductility of polymers and the different approaches to the forming of intractable polymers.

Among the techniques considered were the rolling of oriented polymers, forming under pressure, wet processing, plasticizing, insitu polymerization of monomers, other direct growth processes such as deposition and casting and powder metallurgy techniques. The memorandum lists some recommendations concerning these techniques.

SUMMARY OF MEETING ON THE STATUS
OF METAL-MATRIX COMPOSITES

M. B. Bever and P. E. Duwez

ABSTRACT

A one-day meeting was devoted to a review of the status of metal-matrix composites. This review was conducted through prepared presentations by five speakers who discussed specific cases with which they were closely associated. General current practice and trends and problems bearing on the future development of metal-matrix composites were covered in an extensive systematic discussion.

DEGRADATION OF MATERIALS IN ENERGY-RELATED SYSTEMS IN THE PRESENCE OF HYDROGEN

J. P. Hirth and H. H. Johnson

I. ORGANIZATION AND PURPOSE OF THE MEETING

A three-day meeting on "Materials Problems Relating to Hydrogen in Metals" was held on 10-12 July 1974 at the summer conference of the ARPA Materials Research Council in La Jolla, California. The purpose of the meeting was threefold: (i) to assess the status of hydrogen degradation problems in current energy-related technology, (ii) to pinpoint or anticipate possible problems in prospective new energy technology, with respect to current materials and required development of new materials, and (iii) to delineate areas of greatest importance for future research.

The attendees, representing a spectrum of viewpoints, were as follows:

C. F. Austin, China Lake Naval Weapons Center
A. Bement, Massachusetts Institute of Technology
B. F. Brown, American University
W. T. Chandler, Rocketdyne Division, Rockwell International
M. Cohen, Massachusetts Institute of Technology
I. Cornet, University of California, Berkeley
R. A. Craig, Battelle Columbus Laboratories
D. C. Drucker, University of Illinois
H. Ehrenreich, Harvard University
A. Elsea, Battelle Columbus Laboratories
J. J. Gilman, Allied Chemical Corporation
R. Gomer, James Franck Institute, Chicago
M. F. Hawthorne, University of California, Los Angeles

J. P. Hirth, Ohio State University
R. I. Jaffee, Electric Power Research Institute
H. H. Johnson, Cornell University
H. G. Nelson, NASA-Ames Laboratories
R. A. Oriani, U.S. Steel Corporation
H. W. Paxton, Carnegie-Mellon University
J. R. Rice, Brown University
S. Ruby, Advanced Research Projects Agency
R. W. Staehle, Ohio State University
C. M. Stickley, Advanced Research Projects Agency
A. W. Thompson, Rockwell International Science Center
R. Treseder, Consulting Engineer
E. C. van Reuth, Advanced Research Projects Agency
C. Wert, National Science Foundation

Two sessions at the meeting were held jointly with the group working on "Solar-Energy Systems - Materials Problems" with a correspondingly wider attendance as reported elsewhere in the Report of the Materials Research Council Summer Meeting for 1974.

The following report of the hydrogen meeting is organized in two sections. One portion is a summary of the deliberations, the other is a compendium of individual papers, notes, and comments prepared by attendees. The summary report treats in sequence the definitions of the hydrogen degradation of materials problems with particular emphasis on problems related to hydrogen energy systems and geothermal energy systems; key issues relating to hydrogen problems; a state-of-the-art summary of materials capabilities with respect to hydrogen exposure; and a listing of important areas of research.

SOLAR ENERGY SYSTEMS - MATERIALS PROBLEMS

A. Bement, M. Cohen,
H. Ehrenreich and R. Kaplow

I. ORGANIZATION AND PURPOSE OF MEETING

A four day meeting was held on 8-12 July, 1974, at the summer conference of the ARPA Materials Research Council in La Jolla, California, on solar energy systems as organized by A. Bement, M. Cohen, H. Ehrenreich and R. Kaplow. For two of these days, the program was combined with sessions on hydrogen and corrosion problems, with which there were overlapping interests. A number of persons were invited to give formal presentations in the subject areas of integrated energy systems; photovoltaics; thin-film coatings; hydrogen generation, transmission, and storage; geothermal energy and geothermal related corrosion problems. Four workshops were also scheduled to allow concentration on particular issues of concern to the participants; these dealt with the specific topics of Energy Systems, Photovoltaics, Thin-Film Coatings, and Hydrogen in Energy Systems.

Those who participated in the workshops were:

<u>Energy Systems</u> - A. L. Bement, Chairman

M. Cohen	S. Ruby
D. C. Drucker	M. J. Sinnott
M. F. Hawthorne	D. Spencer
E. E. Hucke	R. P. Stromberg
A. B. Meinel	R. M. Thomson
R. E. Peterson	C. Wert

Photovoltaics - R. Kaplow, Chairman

A. Bienenstock
H. Caspers
H. Ehrenreich
A. K. Ghosh
J. J. Gilman
R. Gomer
M. F. Hawthorne
A. Josephson
W. Kohn
N. Laegreid
E. W. Montroll
P. Rappaport
H. E. Rast
H. Reiss
D. Schueler
A. J. Sievers
T. Wolfram

Thin-Film Coatings - A. J. Sievers, Chairman

A. Bienenstock
N. Bloembergen
H. Ehrenreich
R. Kaplow
W. Kohn
N. Laegreid
P. L. Richards
M. Tinkham

Hydrogen in Energy Systems - M. F. Hawthorne, Chairman

M. Cohen
S. Ruby
M. J. Sinnott
R. P. Stromberg
C. Wert
T. Wolfram

The documents in this report are from the program and its workshops, and include: introduction and program schedule; a list of salient points derived from the discussions and workshops; a series of papers which are, for the most part, the documents underlying the oral presentations given at the meeting; review reports of each of the four workshop groups; and a report on a related visit to facilities at the China Lake Naval Base.